

A decision support discussion to select location for vertical farm in Bahrain

Mohamed A. F. Mahdy*^{1,2}

email: mfouadmahdy@hotmail.com

Fatema Hashem³

email: 20163139@stu.uob.edu.bh

¹ College of Architectural Engineering and Design, Kingdom University, Bahrain

² Architecture Department, Faculty of Fine Arts, Alexandria University

³ Department of Architecture and Interior Design, Collage of Engineering, University of Bahrain

* Correspondence: email: mfouadmahdy@hotmail.com

Abstract

During the 21st century, food security has become a significant concern due to the growing population and the Earth's diminishing resources. The Kingdom of Bahrain is one of the numerous countries that has been affected by urbanization, where the urban expansion was at the price of agricultural land. The paper introduces a rationale for Vertical Farms that are sustainable solutions for 21st- century urbanization. It brings multiple benefits to Bahrain and its community in terms of food security, education, awareness, and health. It also supports its food security strategy and its 2030 vision. The study discusses the proposed project location in terms of the project's needs as an urban vertical farm that aims to serve locals & residents of Bahrain by improving the quality and quantity of locally grown fruits and vegetables in an indoor controlled environment. The paper discussed various analyzed case studies of comparable type projects to understand better the project's purposes, spaces, technological needs, and other significant features. Then, introducing and discussing a decision support framework for a set of criteria that responds to the primary sustainability pillars have been established to identify the best potential site to assure project success.

Keywords Vertical Farming; Food Security; Sustainable Agriculture; Bahrain; Food Security

Citation: Mahdy, M. A. F. and Hashem, F. (2023).

A decision support discussion to select location for vertical farm in Bahrain. *Journal of Sustainable Cities and Built Environment*, 01(01), 52-82.

Retrieved from <http://jscbe.ku.edu.bh>

DOI: <https://doi.org/10.58757/jscbe.dsds/vfb.004>

Publisher: [KU] Kingdom University.

Editor-in-Chief: Dr. Ashraf M. Soliman

Managing Editor: Dr. Adeb Qaid

Received: 9 November 2022

Accepted: 20 January 2023

Published: 25 January 2023

Copyright: © 2023 by the authors. Licensee KU, Manama, Kingdom of Bahrain. This article is an open access article distributed under the terms and conditions of kingdom University license.

1. Introduction

Cities all around the world are quickly expanding and urbanizing. According to the United Nations, those cities are growing in number and density due to population increase and the shift from rural to urban areas [1]. As a result of the population shifts and growth rate, other changes in land usage, economic activity, and culture have occurred [2]. 55% of the world's population live in cities. According to the United Nations, urbanization is predicted to rise to 68% by 2050 because urban population expansion is anticipated to reach 9.8 billion people by 2050 [1]. The growing population means an increasing demand for food. Food production must grow as the population increases to avoid world famine [1]. However, due to the accelerating population growth and urbanization, agricultural land continues to be lost [2], along with increased pollution and environmental deterioration, which impacts available agriculture [3]. Moreover, most cities will suffer from the urban heat island phenomena [4]. According to a recent study, over 33% of the world's sufficient or high-quality food-producing land is being destroyed at a rate that significantly outpaces natural processes to replenish depleted soil [5]. Kingdom of Bahrain is one of the numerous countries that has been affected by urbanization, where the urban expansion was at the price of agricultural land [6]. It resulted in huge losses of traditional agricultural lands [7]. Arable lands in Bahrain have decreased from 6400 hectares to 2400 hectares due to the urban sprawl and the exploitation of extensive agricultural lands for housing projects by the housing ministry [8]. According to initiative Bahrain 2030, the government adopt project Urban Vertical Farm that aims to serve locals & residence of Bahrain by improving the quality and quantity of locally grown fruits and vegetables in an indoor controlled environment. There are two authorities concerned with sponsoring such projects in Bahrain such as National Initiative for Agriculture Development (NIAD) which is the leading player that cares about such a project. The initiative intends to increase the agricultural sector's contribution to GDP (Gross Domestic Product) to attain food security. It supports Bahrain's strategies to maintain agricultural development and expand green spaces by collaborating with the public and private sectors, supporting, and encouraging agricultural activities and projects, proposing the most up-to-date agricultural techniques, and encouraging and supporting scientific research studies in the field of agriculture. Also, the Ministry of Works, Municipalities Affairs, and Urban Planning supports and strives to enhance the agricultural industry and make it more responsive to society's current and future needs by offering

high-quality planning, municipal, and agricultural services in collaboration with government agencies [9]. Selecting a site for Vertical farms or such projects in Bahrain must be thoroughly researched and assessed. Therefore, based on the project's design requirements, literature, and case studies, that a set of criteria is needed to identify the best potential site to assure project success.

1.1 Research Justification & Objectives

1.1.1 Research Justification

The research highlights the problems that face the Kingdom of Bahrain due to its being heavily reliant on imports for its food needs. Roughly 90% of its food requirements are imported goods. It also resulted in food being expensive when compared to local production. Also, it resulted in food security problems, especially in times of crisis like the pandemic, when food imports get stopped [10]. According to Bahrain 2030 initiative, the research aims to produce a recommendation for the mean authorities for the best location of vertical farm in Bahrain. The research also spot the light on the problem of food security for cities after the experiences of the lockdown due to COVID 19 and the economical drawbacks and the recent shortage of food supply due to the wars between countries that export a substantial percentage of foods to other countries. As Bahrain's percentage of arable land decreases year after year, a Vertical farm will be extraordinarily beneficial and significant. It will have the advantages of growing a large quantity of healthier and cleaner crops in a short time and little area, therefore encouraging local production, and reducing reliance on imported products. Moreover, this research addresses how the vertical farm can enhance the sustainability pillars in cities and the site selection criteria for vertical farms within the urban context.

1.1.2 Objectives

Respecting the sustainability concept and matching with Bahrain vision 2030, the paper intends to highlight the importance of the location of vertical farming to achieve the following objectives:

- a) Economic objectives are to:
 - Ensure affordable & non-expensive crops by reducing transportation expenses by selling directly to the consumer.

- Attract tourists & visitors to the project to spread awareness, generate income and support the economy.
- b) Socio-economic objectives are to:
- Create job opportunities for Bahrainis.
 - Increase the awareness of vegetation at buildings.
 - Reduce the cost of cooling in buildings.
 - Increase the economic sources for families.
- c) Environmental objectives are to:
- Conserve natural water.
 - Reduce the carbon footprint & recycle waste by creating a complete food chain & using renewable energy.
 - Minimize the effect of climate change by pursuing and encouraging green recovery & ecosystem restoration.
- d) Social & cultural objectives are to:
- Create a place where people have direct communication with nature which has a positive effect on mental health.
 - Spread awareness among people regarding food security problems & the side effects of conventional farming.
 - Maintain the locals' health by producing clean, healthy & organic crops free-of chemicals by different means of growing techniques & systems in the vertical farm.
 - Engage the community in farming activities to learn more about the importance & benefits of healthy agriculture.
 - Gather the community in a space with different activities to build stronger & healthier relationships between locals for better social wellbeing.

2. Methodology

The research is divided into two sections, the first section is primarily literature on the topic, defining and describing its nature, its justification and necessity. Also, the vertical farm's goal and objectives, and the project's users and prospective sponsors. The section covers three analyzed

case studies of comparable type projects to understand the project's site selection criteria, spaces, technological needs, and other significant features considering community engagement and other objectives. This section led to addressing the three primary aspects of sustainability, including social, economic, and environmental which, in relation to site selection criteria, were developed based on these factors to ensure their achievement. Then, section two develops what concluded from the investigation of the three case studies for the discussion of the three suggested locations in Bahrain for the project vertical farm. The selection criteria are designed to be based on discuss data collected for each site and link it with site significance summaries from case studies and conducted interviews and questionnaires. The interview and questionnaires aim to understand the public needs and demands regarding the facilities and site location to serve the community as needed in objectives. The discussion for each location develops various criterion linked with sustainability pillars. Each location produces a score to decide which location of the three has the potential to be considered as the location of vertical farm. After examining the three sites and assessing each one considering the selection criteria, the selected site will be addressed based on its gained points. Therefore, S.W.O.T analysis will be applied to this site to verify the suitability of the location for such a project.

3. Results & Discussion

3.1 Literature of socio-economic impact of vertical farms on communities

3.1.1 Reasons to build vertical farms & their advantages

- *Food security*

Because of the growing population and the current pandemic, food security has become a sufficient concern in the twenty-first century. According to the UN, by 2050, the world's population will grow by 40%, surpassing 9 billion people. As a result, by 2050, 70% more food will be required to fulfil the needs of an additional 3 billion people on the planet. It also predicts that cities would host 80% of the world's population [1]. As a result, urban sprawl will continue to consume more and more agricultural lands. And as mentioned previously, Bahrain suffers from a lack of arable lands and that 90% of its food requirements are imported [10]. The kingdom of Bahrain could face a severe problem if food import is stopped due to a crisis.

- *Climate change*

Agricultural lands have decreased globally due to climate change, resulting in crop failure and global economic damage. Climate change, and the resulting bad weather conditions, are expected to accelerate, according to scientists. Moreover, traditional farming activities contribute to climate change by requiring large amounts of fossil fuels to carry out agricultural activities [11].

- *Urban density*

According to studies, designating an urban land for conventional farming reduces population density, and lower density living consumes more energy and pollutes the air and water due to food transportation [11].

- *Human & Environment Health*

Profit and economic gain are frequently prioritized in traditional agricultural techniques, with little regard for the harm done to human and environmental health. Erosion, soil contamination, and excessive water waste are all expected outcomes of these activities [11]. In terms of human health, the World Health Organization estimates that more than half of the world's farms still use raw animal excrement as fertilizer, which can attract flies and carry weed seeds or illnesses passed to plants. As a result, consuming such products harms people's health [12]. Furthermore, when extra fertilizer is washed into the water, eutrophication occurs, resulting in a high concentration of nutrients that might disrupt the ecological balance. Moreover, traditional agricultural operations consume more than two-thirds of the world's freshwater. And as water needs will rise as the urban population increases, the water problem will likely worsen as climate change brings higher temperatures and more droughts that lead to losing more agricultural lands [11].

- *The Ecosystem*

“Farming has disrupted more natural processes than any other activity—it is the most damaging process on the planet,” says Despommier [13]. Many forests and natural lands worldwide have been sacrificed to become farmlands for the commercial production of crops. This destructive process of traditional farming has impacted the world’s ecosystem in the worst way [11].

- *Economy*

Traditional farming is becoming more and more expensive, closing the cost gap between it and vertical farming. In addition, it lowers transportation, refrigeration and storage expenses which can account for up to 60% of costs. It also makes use of advanced technology and intensive farming methods to boost crops production. As an outcome, it will provide competitive food pricing, earn more revenue and offer an opportunity to support the local economy [11].

- *Community Knowledge*

Urban residents lost touch with nature and lost sight of the importance of farming. They have no idea where or how food is produced or delivered [14]. Producers have grown increasingly reliant on strong, profit-driven, unsustainable businesses to transport many products from industrial farms into our marketplaces, without regard for nutritional qualities or health [15].

3.2 Case studies adopted community-based approach to design Vertical Farms

It is vital to study similar Vertical farms projects world-wide. The community-based approach to design projects that are held to guidelines could enable the implementation of such projects in Bahrain which are taking into consideration the community. Therefore, examples from applied projects as case studies of a similar approach have been reviewed to expand knowledge and arrive at a successful strategy to achieve the proposed objectives. These examples were selected from different parts of the world to show the linkage between community and the practical approach, regardless of the weather.

3.2.1 Vertical Harvest Urban Farms, USA

Vertical harvest urban farm project, which was constructed in 2016 in an area of approximately 12,138 square meters, is specializing in hydroponic farming, see Fig. 1. This approach consumes less water, land, and energy, making it a more environmentally friendly food production technique. It produces 45 tons of fresh produce per year. Therefore, it may be thoroughly investigated before being implemented in the project. Moreover, the project engages staff with special needs and the community in farming and disseminates awareness & education, which is one of the proposed project goals [16].



Figure 1. Vertical harvest urban farm exterior perspective [16]



Figure 2. Viewing platform, the Vertical harvest urban farm [17]

The conceptual approach of the project emphasized three agricultural concepts that combined to achieve project goals and grow in harsh weather: a greenhouse, vertical farms, and hydroponics, see Fig. 2. The greenhouse solves the apparent challenge of growing food year-round in a harsh environment, and vertical farming allows three separate microclimates to be maintained for space efficiency and diversity. The project strives to feed the residents of Jackson, Wyoming, throughout the year by providing locally grown organic fruits and vegetables, even though it's freezing winter. The concept of community service encompasses more than just feeding Jackson's people; it also aims for public education and employment of as many individuals with intellectual and developmental disabilities as possible, given Wyoming's 78 per cent unemployment rate - empowering unique people to become leaders and innovators in one of a community's most essential aspects: local food production [17].

- *Climate Data*

Summers in Jackson, Wyoming, are hot, dry, and typically clear. It has adverse weather occurrences in the winters, with temperatures below freezing, snowfall, and partially cloudy skies. The temperature ranges typically from -15°C to 26°C throughout the year, with temperatures rarely falling below -25°C or rising over 30°C [18]. To put it another way, the conditions in Jackson are not suitable for agriculture, which led to import for its food requirements [19].

- *Building Components*

The project consists of 3 floors, a public ground floor and two hydroponic producing floors on top, allowing the chilly, landlocked city to offer locally grown fruit to its people all year [20]. The ground floor serves as an educational area for the public. It contains a specialty crop production zone that functions as a living classroom and a training area, along with a living wall atrium and access for visitors to see the growing regions without polluting the crops. It also consists of a sending/receiving area and a preparation area where the crops are packaged and sold in the community marketplace [16]. Furthermore, the farm's creators have made it a point to grow only fruit that is currently imported, ensuring that the farm does not compete with local farmers and, instead, helps local companies by reducing transportation expenses [20]. The horizontal circulation in the center of the project follows a U-shape circulation that is kept as a viewing platform for visitors, separate from cultivation areas to avoid contamination [16]. The building façade design is providing a clear view to the inside, showing the attractive green color of plants which will attract visitors to visit the project and learn more about vertical, organic food production [21]. Along with the hydroponic system, the project uses vertical rotating growing carousels, see Fig. 3 & Fig. 4. As the developing plants move along the system, they receive an equal quantity of natural and artificial lighting, reducing the building's energy use. This technology will also deliver planting and harvesting trays directly to the individuals, in this case, the employees with developmental impairments, see Fig. 5. This project shows how the public can be engaged in farming activities by dedicating separate and unique facilities to attract people and spread knowledge.

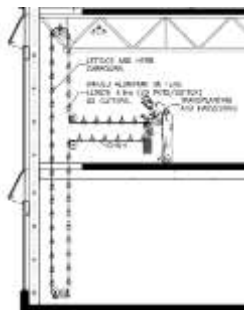


Figure 3. Detailed section showing vertical growing carousels [16]



Figure 4. Vertical growing carousels technology [20]



Figure 5. Harvest trays considerate for people with special needs for easy harvest [17]

3.2.2 Food Farm Tower/Agro Main Ville, France

The project is located in Romainville, the eastern suburbs of Paris, France. The city of Romainville is known for its high-density urbanization, which resulted in farmland shortage and, therefore, a shortage in food production. Thus, the project was introduced to support local food production [22].

- *Climate Data*

Summers in Romainville are short, the temperature generally ranges from 2°C to 26°C throughout the year, with temperatures rarely falling below -4°C or rising over 31°C [23]. It means that throughout winter cultivating is challenging due to the weather events.

- *Building Components*

To achieve the project goal, which is to increase crop output and diversity, the building was made as a vertical tower in the form of a ziggurat, stepped towards the south to be fully immersed in the sun, see Fig. 6. As a result, the designers optimized plant exposure to sunshine while also situating the project on a small parcel of land in a crowded neighborhood. In addition, the architects created an emergence between architecture and nature, creating an exciting form that can be easily grasped by the visitors and accepted by the residence of Romainville due to the integrated communal garden space [24].



Figure 6. Food Farm Tower exterior perspective [27]

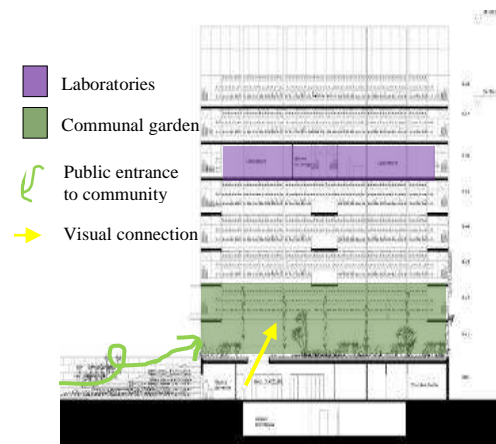


Figure 7. Longitudinal section of Food Farm Tower [27]

The section, see Fig. 7, clearly shows the different levels of the project. It also shows the visual connection between the ground floor and the community garden above it, which created a strong

relationship and link between the two floors. Moreover, it shows the public access made from the ground level up to the communal garden, which aims in attracting visitors to visit the project and spread knowledge, along with being accepted by locals. To maintain the project's sustainability, green waste, whether from the project itself or the residents, is collected for on-site composting and then used as fertilizers to keep a healthy soil for crop production. Moreover, the excess waste, which can't be used as fertilizer, is burned, and the energy generated is used for regulating the temperature within the building [25].

3.2.3 Agrotopia Rooftop Greenhouse

This project was selected because it is a vertical farm and a research space containing facilities that involve the community to experience farming and encourage them to participate in research, see Fig. 8. It also implements different technologies, sustainable methods, and a simple, creative design that reduces energy requirements and attracts visitors.



Figure 8. Agrotopia rooftop greenhouse exterior perspective [28]



Figure 9. Interior perspective showing the educational route A [28]



Figure 10. Interior perspective showing the educational route B [28]

The project's primary objective was to create a space for training, information, and education, supporting urban food production and developing farming and cultivation techniques to develop further and increase crop production [26]. Furthermore, the project aims to create sustainable soilless agriculture throughout the integration in a visible built environment to attract as many visitors as possible to the facility to be involved and engaged in the farming and research process and spread knowledge among the public. A space where producers and consumers can meet and can work together [27]. The Agrotopia rooftop greenhouse is a research facility and a vegetable-growing exhibition constructed on an existing warehouse roof, integrating the agricultural and horticulture research institution, Inagro, with the logistics sector and the public, see Fig. 9 [28].

- *Building Components*

The high-tech research facilities, which are for the cultivation of fruits and leafy vegetables, are surrounded by this educational visitor route. The form of loop circulation is for an educational experience, see Fig. 10. The cultivation areas were used as central modular blocks, arranged to be surrounded by corridors from all sides because the corridors were used as a climate buffering zone along with their function for circulation [27] .

3.2.4 Lessons learnt

The illustrated examples (case studies) have shown their commitment to the goal of supporting local food production and at the same time educating the community, all within an environment-friendly structure. Moreover, the case studies have shown that vertical farms can also be sustainable due to the different technologies used in farming, resulting in the minimum waste possible. Furthermore, it stressed the importance of evolving and engaging the community further to enhance their knowledge and acceptance of the project, all through the provision of different facilities. Vertical farms address the three primary aspects of sustainability, including social, economic, and environmental.

Table 1. Case studies’ site significance.

Case study	Location	Site significance summarized from case studies.
Vertical Harvest Urban Farm	Jackson, Wyoming, USA.	<ul style="list-style-type: none"> • Its location is in a dense mixed-use urban area that suffers from a shortage in local food production and a high dependency on food imports. • It is surrounded by secondary roads, making it quickly reached, accessible, and visually noticed by visitors. • The longest side on the plot is facing south which provides maximum solar penetration that aids plants growing requirements.
Food Farm Tower / Agro Main Ville	Romainville, Paris, France.	<ul style="list-style-type: none"> • Its location is in a highly dense urban area that lacks farmlands and, therefore, a shortage in food production & supply. • It is surrounded by secondary roads & pedestrian walkways, making it easily accessed and visually perceived from all sides. • Along with the pedestrian walkways, the architects integrated a communal garden to attract passersby to the project.
Agrotopia Rooftop Greenhouse	Roeselare, Belgium.	<ul style="list-style-type: none"> • The architects designed the project as a landmark located in the center of the city and surrounded by highways. These primary and secondary roads made it easily reachable, accessible, and visually seen from different sides and angles. • Along with its location in the city, it became closer to commuters and distribution markets to supply crop production.

Tab. 1 reviews lessons learnt from case studies to create criteria, which were developed based on these factors to ensure their achievement. The table below summarizes the essential site features obtained from the Vertical Farms case studies discussed in Chapter three.

3.3 Site Selection

3.3.1 Criteria concluded from case studies

Vertical farms, as determined by the case studies, refer to bringing natural green spaces to the heart of cities to reduce the distance between people and their food source while also restoring the natural environment. As a result, such a project has to be constructed closer to individuals, on a leading site in a surrounding urban context with a solid connection to transportation routes making it easily accessible and easily visible from many locations to attract more visitors and spread awareness.

Tab. 2 summarizes site selection criteria linked to sustainability pillars.

Table 2. Site selection criteria

Category	Criteria	%
Environmental Aspect (Urban and manmade – nature – climate consideration)	Lacks natural greenery: the project aims to bring people closer to nature & their food production. Therefore, the location has to be in an urban area that lacks vegetation & farmlands.	10%
	Openness & exposure to natural sunlight: The selected site has to be surrounded by open areas to allow the maximum & direct exposure to sunlight required for plant growth to reduce energy consumption. Also, to provide a clear view of the project.	15%
	Surrounding environment & Outdoors' Potentials: The project is related to crops, plants & landscape. Therefore, it must be located in an area with suitable environmental conditions away from pollution sources to undertake cultivation, landscape, and outdoor activities safely.	10%
	Closer to distribution markets: The site is preferable to be near distribution markets such as; supermarkets, retail centres, etc. to reduce crop's transportation distances and, therefore, related pollution & costs.	5%
Economic Aspect (job opportunity – transportation costs, etc.)	Visibility: The site must be visible from a major highway or a heavily trafficked region, enhancing its chances of attracting passersby, whether pedestrians or automobiles, to achieve its goals.	15%
	Landmark Potential: The site must allow the project to stand out and have a solid & unique presence within its surrounding area to attract visitors further.	10%
	Area: The selected site area must respond to the project program, requirements, and other required criteria.	5%
Social Aspect	Urban dense areas & Closer to consumers: the project is mainly designed for the public. Therefore, the location has to be in a residential or mixed-use space that is active, dense, away from farmlands and closer to distribution markets; to allow the public to be closer to their food source and allow a heavier flow of visitors.	15%
	Public Accessibility & Transportation: Vehicles and pedestrians should easily reach the site, and the site also should be adequately connected to major public transportation networks.	15%

3.3.2 *Criteria concluded from interviews and questionnaires*

According to the survey conducted see appendix 01, which aimed in understanding the public’s needs and demands regarding the facilities and site location, almost all selected a site in the capital governorate, which indicated that the location of the Vertical farms must be in an active, viable and famous area that people highly visit. Moreover, as the public prefers more outdoor spaces, the site must be located in a safe environment that allows outdoor activities to be conducted safely.

3.3.3 *Site selection criteria*

As Vertical farms address the three primary aspects of sustainability, including social, economic, and environmental, site selection criteria were developed based on these factors to ensure their achievement. It can be summarized from Table 2 that the proposed site should include several factors to ensure sustainability, including social, economic, and environmental. Key factors for location must be in an urban area that lacks vegetation & farmlands. The site is preferable to be near distribution markets such as supermarkets, retail centers.

3.3.4 *Potential sites*

- *Site A (Al-Sanabis)*

Location: Al-Sanabis, Capital Government.

Site Area: 42,669 Square meters.

Land cost: Approx. 26,625,456 BD [29]

The reason behind selection: the site is located in Al-Sanabis, a mix-use area that attracts many visitors & tourists around the year. The location is also near the highway where many people pass by every day, which results in a prominent site that will attract visitors and help spread awareness among many people; see Fig. 11 & Fig. 12.



Figure 11. Site A location map [31]



Figure 12. Site A panoramic East view

Table 3. Site A criteria rate

Category	Criteria	Advantages & Disadvantages of the site	Rate	%
Environmental Aspect	Lacks natural greenery	Disadvantages: The site lacks natural green cover and green spaces, which results in high temperatures. Advantages: A Vertical farm would be a great idea as a green space to lower the temperature and bring people back close to nature.	10%	10%
	Openness & Exposure to natural sunlight	Advantages: An adequate open space surrounds the site. Therefore, it is highly exposed to natural light, which ensures crop growing requirements & a lower energy consumption (less use of artificial lighting).	13%	15%
	Surrounding environment & Outdoors' Potentials	Disadvantages: The site is surrounded by roads from all sides. Therefore, landscape and vegetation must be incorporated to clean the air from cars resulting in pollution.	7%	10%
	Closer to distribution markets	Advantages: The site is near many supermarkets & cold stores where produced crops can be easily distributed to other markets, reducing transportation distances, and becoming closer to consumers.	5%	5%
Economic Aspect	Visibility	Advantages: The site is directly over-viewed by the main highway where many people pass every day. Its location is near Bahrain mall and the exhibition's center, which are famous places in Bahrain.	15%	15%
	Landmark Potential	Advantages: As the site is overlooking the highway, and the area lacks greenery, and all surrounding buildings are of medium rise, the project has a high percent in standing out and becoming a landmark.	8%	10%
	Area	Advantages: The site is of a good area that fits the project program & requirements.	5%	5%
Social Aspect	Urban dense areas & Closer to consumers	Disadvantages: The site is located in a dense, mix-use active urban area that lacks farmlands and, therefore, lacks organic crops and green regions. Advantages: The Vertical farm would help bring people closer to their food source and further spread awareness regarding the importance of local agriculture.	15%	15%
	Public Accessibility & Transportation	Advantages: The site can be easily accessed by vehicles and pedestrians as it is connected to public transportation route.	14%	15%
Total			92%	100%

A decision support discussion to select location for vertical farm in Bahrain

Moreover, the site is also near a residential area where the project would become closer to consumers. In addition, the site is in a dense urban fabric that lacks greenery and suffers from high temperatures. Therefore, the project will create a place that connects people back to nature. Tab. 3 summarizes site A criteria rate linked to sustainability pillars.

- *Site B (Al-Seef District)*

Location: Al-Seef District, Capital Government.

Site Area: 43,936 meters square.

Land cost: Approx. 23,637,568 BD [29]

The reason behind selection: the site was selected based on its active location, which overviews the highway, see Fig. 13 & Fig. 14. Its mixed use, highly visited area provides the advantage of attracting visitors to the project and, therefore, achieving the project's goal of spreading awareness. Moreover, as the region lacks greenery and contains highly dense concrete buildings and high traffic areas, which results in high temperature, a Vertical farm and landscape can help in reducing the temperature and creating a colder environment in the middle of the city. Tab. 4 summarizes site B criteria rate linked to sustainability pillars.



Figure 13. Site B location map [31]



Figure 14. Site B panoramic East view

Table 4. Site B criteria rate

Category	Criteria	Advantages & Disadvantages of the site	Rate	%
Environmental Aspect	Lacks natural greenery	Disadvantages: The site's location is in an area that highly lacks natural greenery as it is a commercial area. Advantages: The Vertical farm would add greenery to the area.	10%	10%
	Openness & Exposure to natural sunlight	Advantages: The site is surrounded by roads and a highway, resulting in an open space and high exposure to natural sunlight.	12%	15%
	Surrounding environment & Outdoors' Potentials	Disadvantages: As the site is surrounded by roads from all sides and located in a commercial space, the space might not be safe for outdoor activities due to high pollution and noise.	5%	10%
	Closer to distribution markets	Advantages: The site is close enough to distribution markets.	3%	5%
Economic Aspect	Visibility	Advantages: As the site is located in a high visited area, surrounded by roads and a highway, and tall rise buildings, the site is visible from all sides.	15%	15%
	Landmark Potential	Disadvantages: As the site is located in a dense area and has surrounding high rise buildings, the project has a low percentage of standing out and becoming a landmark.	5%	10%
	Area	Advantages: The site is a good area that fits the project program.	5%	5%
Social Aspect	Urban dense areas & Closer to consumers	Disadvantages: The site is located in a high-density urban area that lacks farmland and green spaces. Advantages: Due to the high per cent of passersby every day and adequate surrounding residential towers and neighborhoods, the project will provide fresh crops directly to consumers.	12%	15%
	Public Accessibility & Transportation	Disadvantages: The site's location is in a high traffic area that might later result in extra traffic.	10%	15%
Total			77%	100%

- *Site C (Karababad)*

Location: Karababad, Capital Government.

Site Area: 22,393 meters square.

Land cost: Approx. 12,047,434 BD [29]

The reason behind selection: the site was selected based on its location near a residential neighborhood where people can have direct access to healthy crops produced in the Vertical Farm, see Fig. 15 & Fig. 16. Moreover, it was also chosen because of its location near Karababad beach, a highly visited place by many people. Due to the site being visible from the beach, it can attract people to see & discover the project. In addition, it connects to the project's purpose since Karababad was known for its greenery and farms, which have disappeared nowadays because of urbanization. Tab. 5 summarizes site C criteria rate linked to sustainability pillars.



Figure 15. Site C location map [31]



Figure 16. Site C panoramic West view

Table 5. Site C criteria rate

Category	Criteria	Advantages & Disadvantages of the site	Rate	%
Environmental Aspect	Lacks natural greenery	Advantages: The site does not lack a high per cent of greenery as it is near farmlands.	4%	10%
	Openness & Exposure to natural sunlight	Advantages: The site is surrounded by an adequate open space due to the surrounding roads. It is also exposed to natural light required for plant growth.	15%	15%
	Surrounding environment & Outdoors' Potentials	Advantages: The site is located in a clean area, away from contamination sources. Disadvantages: As roads from all sides surround it, vegetation must be introduced to clean the air to create a healthier outdoor space.	8%	10%
	Closer to distribution markets	Advantages: The site is not very close to distribution markets.	3%	5%
Economic Aspect	Visibility	Advantages: The site is located near Karbabad beach, which is a highly visited area. But the site is situated inside Karbabad village and away from the highway.	12%	15%
	Landmark Potential	Advantages: As the site's location is near famous places such as Karbabad beach and Bahrain fort, and as it is related to agriculture, which is the history of Karbabad village, it has a percentage in becoming a landmark.	9%	10%
	Area	Advantages: The site is of a good area that fits the project program.	3%	5%
Social Aspect	Urban dense areas & Closer to consumers	Advantages: The site is located in a dense urban area and directly close to a residential neighborhood, enabling the project to be closer to consumers. Disadvantages: due to the location in a highly dense residential area, the project might cause traffic. Therefore, the site entrance should be carefully located.	15%	15%
	Public Accessibility & Transportation	Advantages: The site is easily accessed by vehicles and pedestrians, and it's connected to public transportation routes.	15%	15%
Total			84%	100%

3.3.5 The selected site

Tab. 6 below discusses why Site A; see Fig. 17 & Fig. 18, is the selected due to its gained points and response to the listed criteria. Furthermore, the discuss for these criteria has been discussed in details in the form of S.W.O.T analysis in section 3.4.

Table 6. Site A is the selected site due to its gained points and response to the listed criteria.

Category	Criteria	Site A	Site B	Site C	Weight
Environmental Aspect	Lacks natural greenery	10%	10%	4%	10%
	Openness & Exposure to natural sunlight	13%	12%	15%	15%
	Surrounding environment & Outdoor Potentials	7%	5%	8%	10%
	Closer to distribution markets	5%	3%	3%	5%
Economic Aspect	Visibility	15%	15%	12%	15%
	Landmark Potential	8%	5%	9%	10%
	Area	5%	5%	3%	5%
Social Aspect	Urban dense areas & Closer to consumers	15%	12%	15%	15%
	Public Accessibility & Transportation	14%	10%	15%	15%
Total		92%	77%	82%	100%



Figure 17. Selected site - Site A

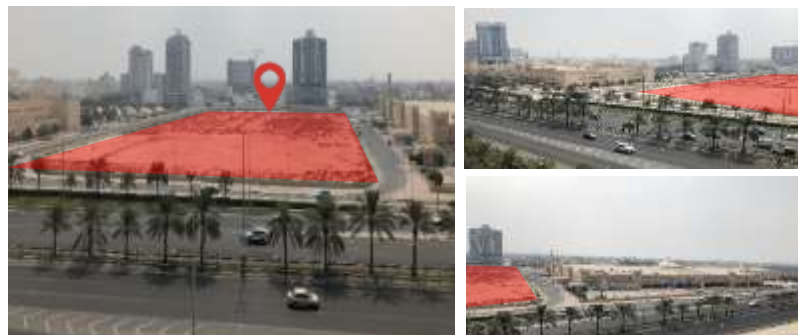


Figure 18. Top views of selected site - Site A

3.3.6 S.W.O.T Analysis of the selected site

After examining the three sites and assessing each one considering the selection criteria, Site (A) was selected due to its gained points. Therefore, S.W.O.T analysis will be applied to this site to verify the suitability of the project. Strengths, Weaknesses, Opportunities and Threats are discussed in Fig. 19, 20, 21 & 22 respectively.

Strengths

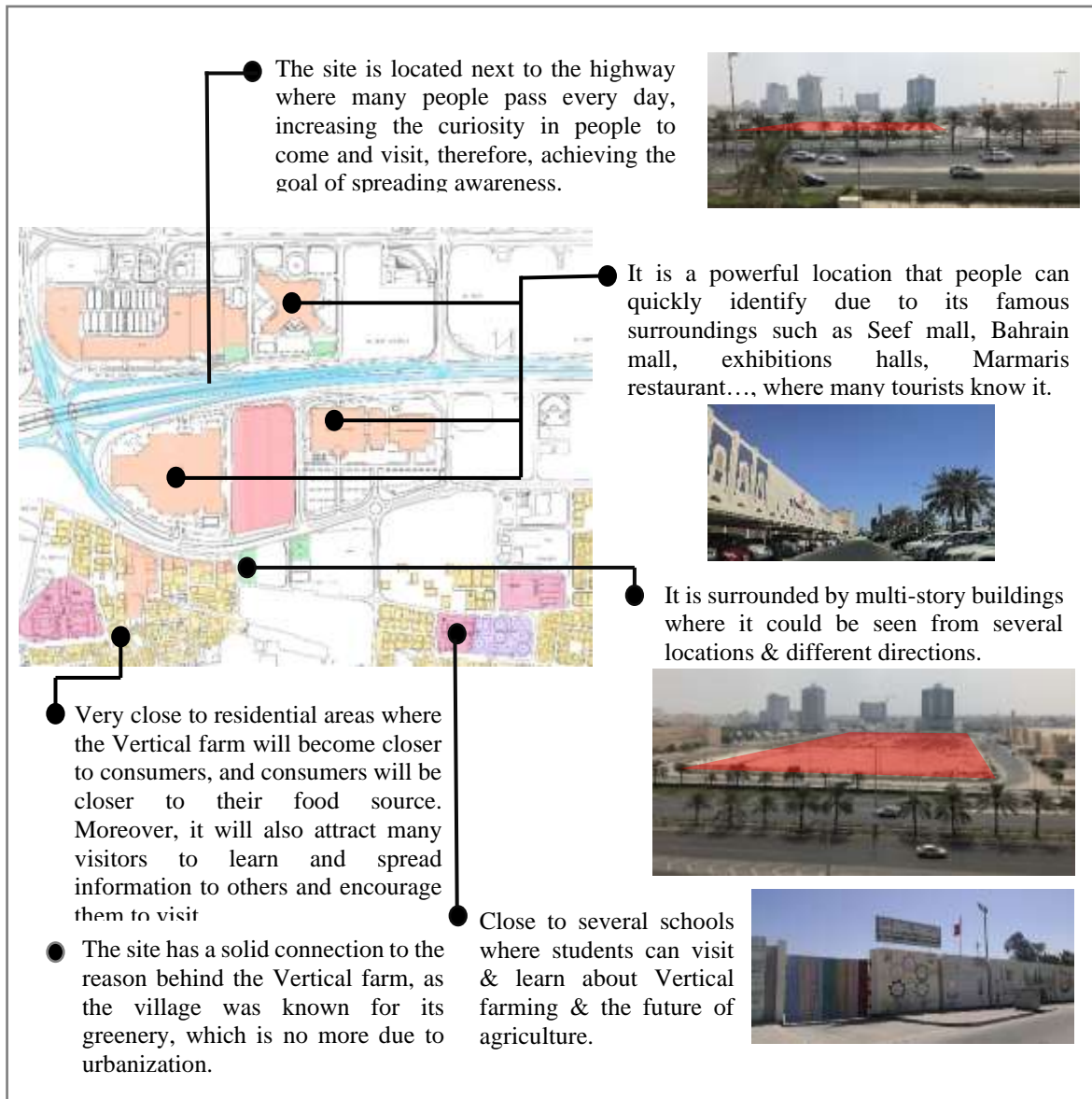


Figure 19. Strength's analysis of selected site

Weaknesses

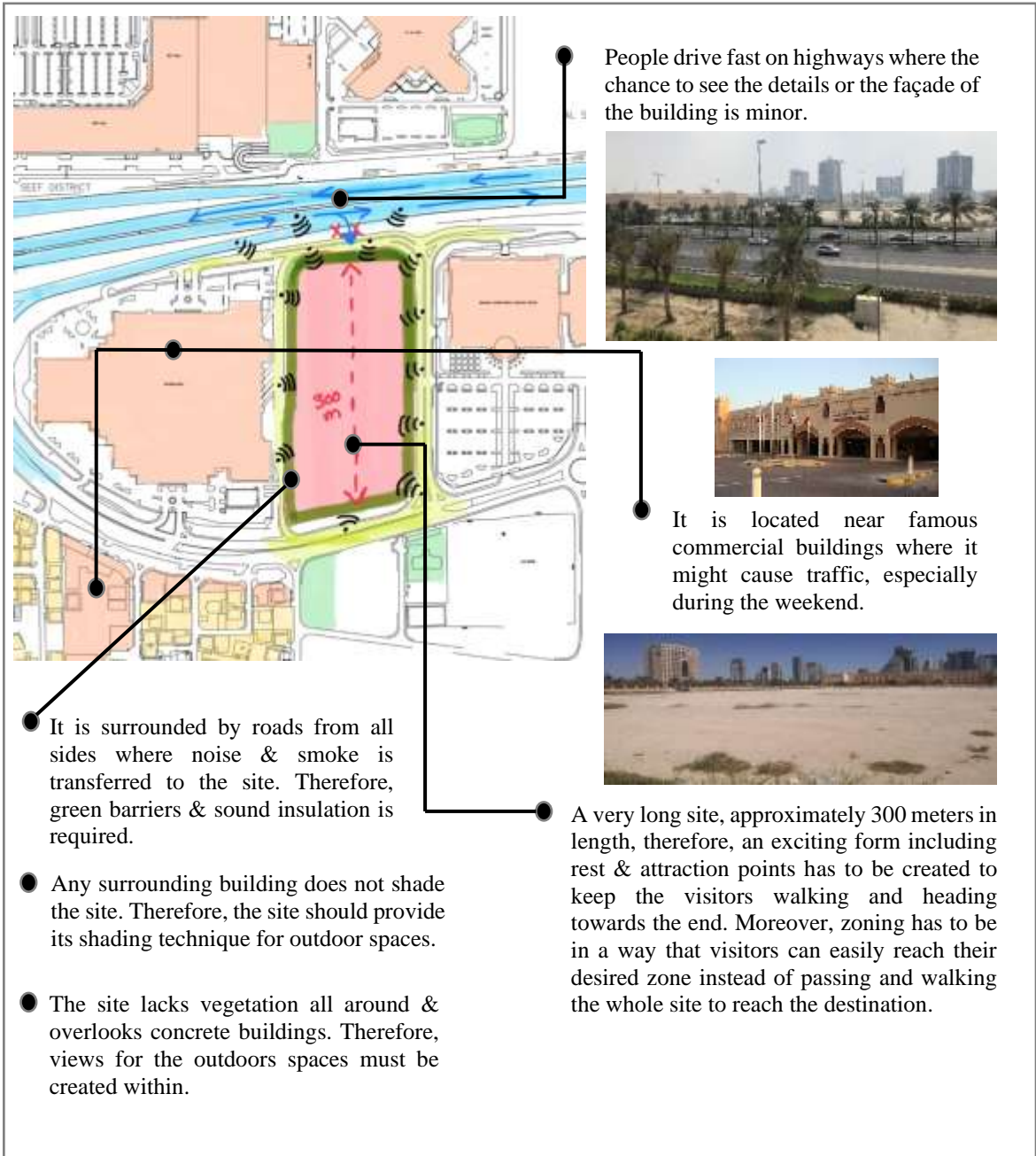


Figure 20. Weaknesses analysis of selected site

Opportunities

- Due to its location, near a residential and commercial area, it can attract many visitors and tourists to the project. And by attracting more people, we can spread knowledge and awareness about Vertical farming, Vertical sustainable farms & the future of agriculture which will achieve project goals.
- Due to its location near the highway, everyone could see it from different directions attracting more people to the site.
- As the site is located in an area that lacks greenery & vegetation and is surrounded by huge concrete buildings, the Vertical farm has a high chance of standing out in between and becoming a landmark.
- The one-way road is already used as a service road for Bahrain mall; therefore, it can also be used as a service road and loading & unloading area for the Vertical Farm.
- One side of the building is already covered with vegetation that can hide the parking area.








Figure 21. Opportunities analysis of selected site

Threats

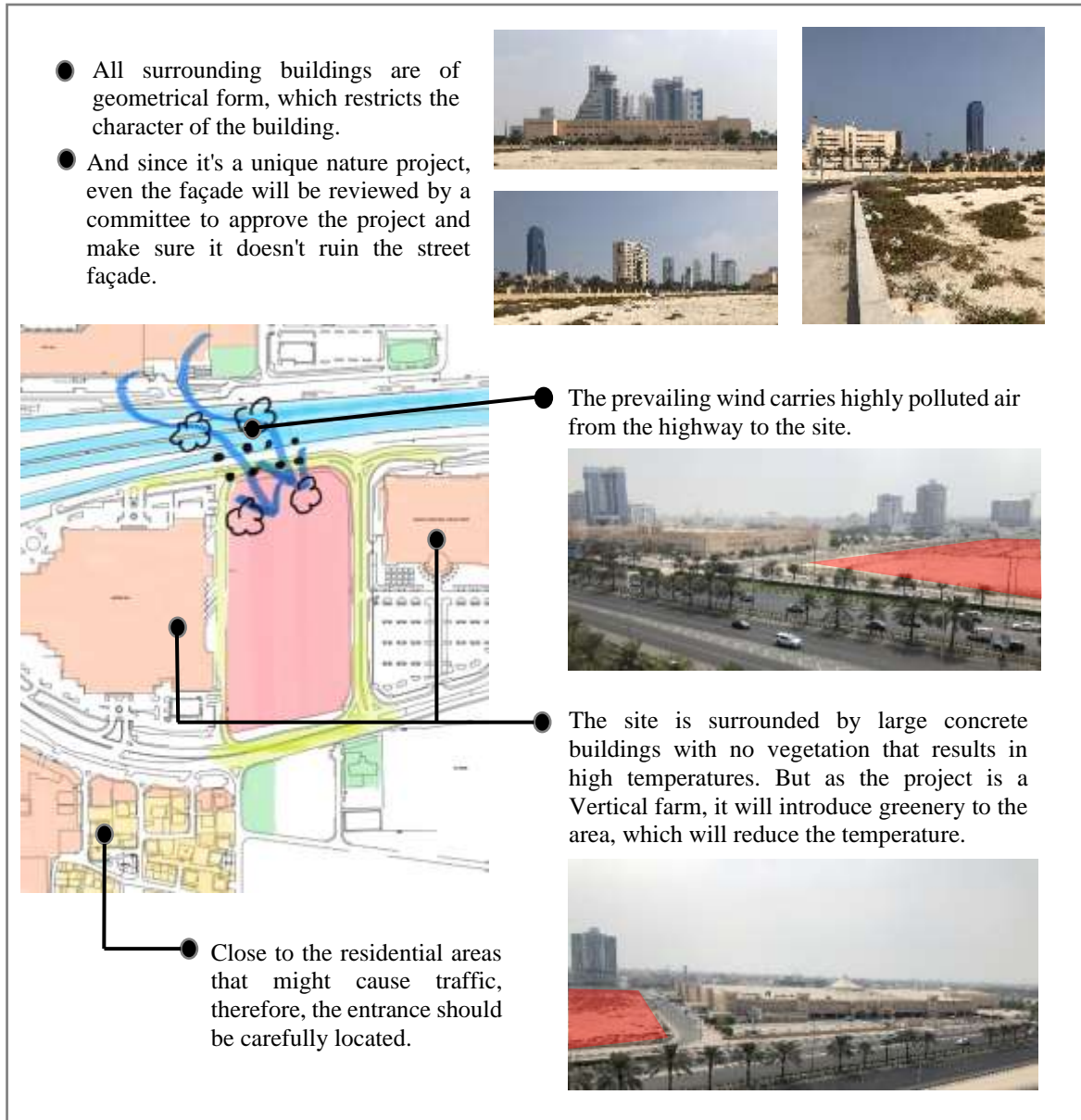


Figure 22. Threats analysis of selected site

3.3.7 Conclusion from S.W.O.T

The site is located next to the highway where many people pass every day, increasing the curiosity in people to come and visit, therefore, achieving the goal of spreading awareness. It is a powerful location that people can quickly identify, the site has a solid connection to the reason behind the Vertical farm, as the village was known for its greenery, which is no more due to urbanization. However, it is located near famous commercial buildings where it might cause traffic, especially during the weekend. A very long site, approximately 300 meters in length, therefore, an exciting form including rest & attraction points has to be created to keep the visitors walking and heading towards the end. Due to its location, near a residential and commercial area, it can attract many visitors and tourists to the project. And by attracting more people, we can spread knowledge and awareness about Vertical farming, Vertical sustainable farms & the future of agriculture which will achieve project goals. As the site is located in an area that lacks greenery & vegetation and is surrounded by huge concrete buildings, the Vertical farm has a high chance of standing out in between and becoming a landmark. All surrounding buildings are of geometrical form, which restricts the character of the building.

4. Conclusion

Vertical Farms hold many advantages, making them sufficient, sustainable structures for food production. As Bahrain's percentage of arable land decreases year after year, a Vertical Farm will be extraordinarily beneficial and significant to supporting Bahrain's food security strategy. Moreover, along with the different technologies used in Vertical farming, depending on the type of crops, a combination of those technologies must be used to ensure year-round crop production, which will have the advantages of holding a positive impact on the health presented, education, and mental health of the community. To match the project's essential objectives and criteria while also improving the user's experience, selecting a site for Vertical farms or such projects must be thoroughly researched and assessed. Therefore, based on the project's design requirements, interviews, questionnaires, case studies and the program needs have already been discussed, along with the past chapters, a set of criteria that responds to the primary sustainability pillars has been established to identify the best potential site to assure project success. According to the survey

conducted, which aimed in understanding the public's needs and demands regarding the facilities and site location, almost all selected a site in the capital governorate, which indicated that the location of the Vertical farms must be in an active, viable and famous area that people highly visit. All case studies have shown their commitment to the same goal of the proposed project, which is supporting local food production and at the same time educating the community. Moreover, the case studies have shown that vertical farms can also be sustainable due to the different technologies used in farming, resulting in the minimum waste possible. Furthermore, it stressed the importance of evolving and engaging the community further to enhance their knowledge and acceptance of the project, all through the provision of different facilities. The project's location is essential, as it determines the accessibility & visibility of the project and the amount of natural sunlight that can be obtained for cultivation. Therefore, the location selected must be easily accessed & visible to attract visitors and surrounded by enough open space to ensure that maximum natural light can be obtained. The form design and orientation are essential to harvest the maximum amount of natural light, reducing energy requirements and ensuring the healthy growth of crops. The project also has to be a landmark to attract visitors to spread knowledge and education. Discussion emphasized through sequence steps that site A in Al-Sanabis has been selected due to its gained points and significant advantages, which matches the selection criteria. To further maintain a successful project, technologies, passive design methods & a renewable energy system has to be selected to gain the maximum benefits from the site to ensure a successful and sustainable project.

Acknowledgement

We sincerely thank Prof Islam Elghonaimy (Department of Architecture and Interior Design, Collage of Engineering, University of Bahrain for assisting with case selection and providing materials related to the site selection. We are also grateful for Dr Dalia Hussein Eldardiry (College of Design, Imam Abdulrahman Bin Faisal University) for her valuable and constructive suggestions during the planning and development of this research work.

References

- [1] U. Nations, "World Urbanization Prospects - The 2018 Revision," 2019. [Online]. Available: <https://population.un.org/wup/>. [Accessed 26 September 2021].
- [2] D. M. G. a. T. C. Satterthwaite, *Urbanization and its implications for food and farming*, The Royal Society Publishing, 2010.
- [3] N. Geographic, "National Geographic," [Online]. Available: <https://www.nationalgeographic.com/environment/article/urban-threats>. [Accessed 26 September 2021].
- [4] I. E. D. H. Elghonaimy, "Greenery in cities and controlling the reasons of Urban Heat Islands, the 25th International Conference on Urban Planning and Regional Development in the Information Society, 15-18 April 2020, Rheinisch-Westfälische Technische Hochschule (RWTH) Aachen, Aa," in *International Conference on Urban Planning and Regional Development in the Information Society*, Aachen, Germany, 2020.
- [5] O. Milman, "Earth has lost a third of arable land in past 40 years," *The Guardian*, 2010.
- [6] I. J. N. Elghonaimy, "Concomitant of global warming and land reclamation: Designing a new interface between human kind and sea," in *International Conference on Industrial Engineering and Operations Management (IEOM)*, Pretoria, South Africa, October, 2018.
- [7] FAO, *AQUASTAT Country Profile – Bahrain.*, Rome, Italy, 2008.
- [8] S. Al-Halwaji, "The shrinking of agricultural areas in Bahrain from 6400 to 2400 hectares," *Al-Wasat newspaper*, 2013.
- [9] M. A. a. U. P. Ministry of Works, "Ministry of Works, Municipalities Affairs and Urban Planning, n.d. Ministry Strategy. [online] Ministry of Works, Municipalities Affairs and Urban Planning. Retrieved from <https://www.mun.gov.bh/portal/pages/StrategyEn.jsp> on 28th September 2021.," [Online]. Available: <https://www.mun.gov.bh/portal/pages/StrategyEn.jsp>. [Accessed 28 September 2021].
- [10] S. Lehane, "Future Directions - Bahrain food and water security," 2015. [Online]. Available: <https://www.futuredirections.org.au/publication/bahrain-food-and-water-security/>. [Accessed 26 September 2021].
- [11] K. Al-Kodmany, *The Vertical Farm: A Review of Developments and Implications for the Vertical City*, MDPI, 2018.
- [12] W. H. Organization, *Animal Waste, Water Quality and Human Health*, London: IWA, 2012.

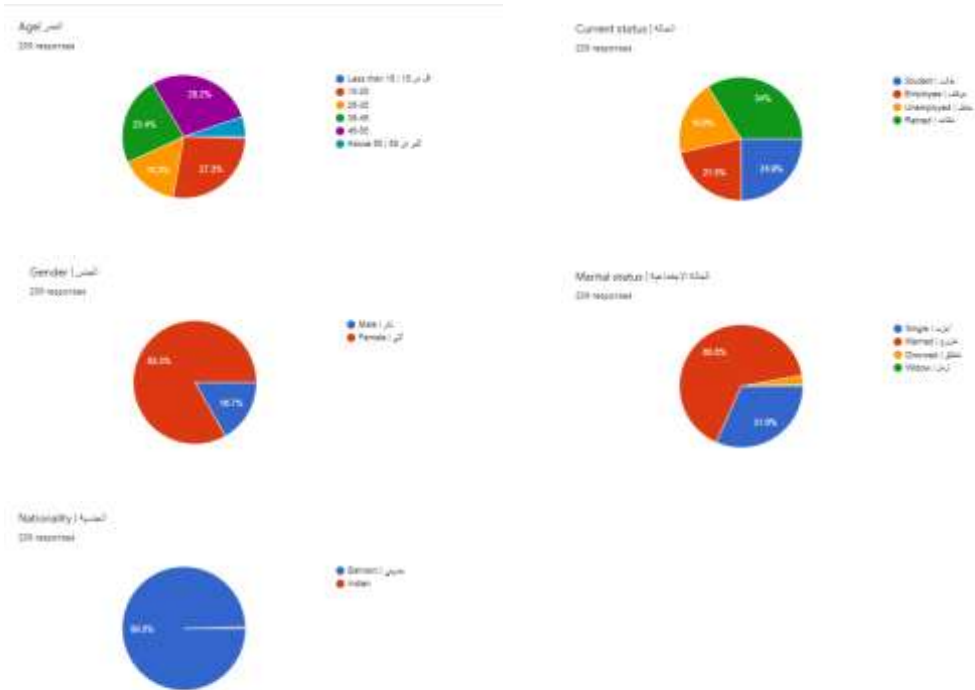
- [13] D. Despommier, "Advantages of the Vertical Farm," in *Springer Optimization and Application*, Springer, 2011.
- [14] F. M. T. O. A. J. R. a. F. E. Kalantari, "Opportunities and Challenges in Sustainability of Vertical Farming: A Review," *Journal of Landscape Ecology*, vol. 11, no. 1, 2017.
- [15] U. o. C. Scientists, "Union of Concerned Scientists," 2008. [Online]. Available: Union of Concerned Scientists, 2008. The Hidden Costs of Industrial Agriculture. [online] Union of Concerned Scien<https://www.ucsusa.org/resources/hidden-costs-industrial-agriculture>. [Accessed 5 October 2021].
- [16] P. a. Y. N. McBride, "Metalocus," Metalocus, [Online]. Available: McBride, P. and Yehia, N., n.d. VERTICAL HARVEST. <https://www.metalocus.es/en/news/vertical-harvest>. [Accessed 10 October 2021].
- [17] G. Olson, "Food and Community Elevated Vertical Harvest Jackson Hole," Olson, G., n.d. Food and Community Elevated Vertical Harvest Jackson Hole. [online] [Ououtpostjh](https://www.outpostjh.com/vertical-harvest-jackson-hole/), [Online]. Available: <https://www.outpostjh.com/vertical-harvest-jackson-hole/>. [Accessed 10 October 2021].
- [18] Weatherspark, "Jackson Climate, Weather," Weatherspark, [Online]. Available: <https://weatherspark.com/y/2902/Average-Weather-in-Jackson-Wyoming-United-States-Year-Round>. [Accessed 10 October 2021].
- [19] G. Henderson, "Bloomberg," Bloomberg, [Online]. Available: <https://www.bloomberg.com/news/articles/2015-02-17/the-case-for-vertical-farming-in-small-town-wyoming>. [Accessed 10 October 2015].
- [20] B. Meinhold, "Inhabitat," Inhabitat, 2021. [Online]. Available: <https://inhabitat.com/vertical-harvest-of-jackson-hole-will-grow-organic-produce-even-in-the-winter/vertical-harvest-eye-design-9/>. [Accessed 10 October 2021].
- [21] M. Provaznik, "Inside Vertical Harvest Farms in Jackson, Wyoming," FineGardening, [Online]. Available: Provaznik, M., n.d. Insi<https://www.finegardening.com/article/inside-vertical-harvest-farms-in-jackson-wyoming>. [Accessed 10 October 2021].
- [22] Projects.archiexpo, "Ziggurat-like vertical farming tower would soak up the sun," Projects.archiexpo, [Online]. Available: Projects.archiexpo.com. n.d. Ziggurat-like vertical farming tower would soak up the sun in Paris by <https://projects.archiexpo.com/project-211953.html>. [Accessed 10 October 2021].
- [23] Weatherspark, "Roeselare Climate," Weatherspark, n.d. Roeselare Climate, Weather By Month, Average Temperature (Romainville, France) - Weather Spark. [online] Weatherspark.com. Retrieved from <https://weatherspark.com>. [Online]. Available:

<https://weatherspark.com/y/47894/Average-Weather-in-Roeselare-Belgium-Year-Round>. [Accessed 12 October 2021].

- [24] World-Architects, "Food Farm-Tower," World-Architects, 2016. [Online]. Available: <https://www.world-architects.com/en/architecture-news/works/food-farm-tower>. [Accessed 11 October 2021].
- [25] Inhabitat, "Agro-main-ville," Inhabitat, 2016. [Online]. Available: <https://inhabitat.com/ziggurat-like-vertical-farming-tower-would-soak-up-the-sun-in-paris/agro-main-ville-by-abf-lab-6/>. [Accessed 11 October 2021].
- [26] "A Review of Vertical Farming as An Approach to Achieve Sustainable Food Security in Bahrain".
- [27] Abf-lab, "Agro-main-ville," Abf-lab, [Online]. Available: <http://abf-lab.fr/projets/agro-main-ville>. [Accessed 11 October 2021].

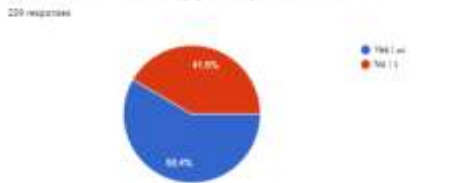
Appendix 01 : Conducted Survey

General Information

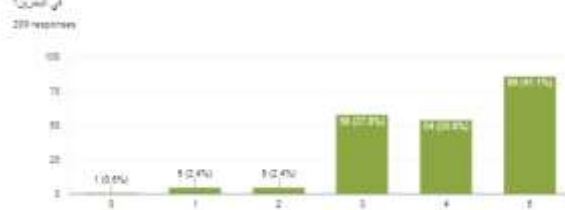


Survey questions & answers

Are you aware of the current food security situation in Bahrain and the threats it comes with?
هل كنت على درية بالوضع الحالي للأمن الغذائي في البحرين وما يستتبعه من تهديدات؟



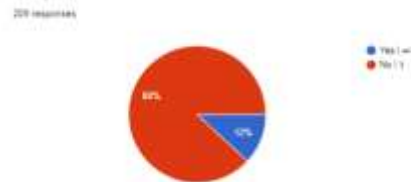
In scale of 5, rate the need of a Vertical farm in Bahrain?
على مقياس من 5، افرم الحاجة إلى مزرعة عمودية في البحرين؟



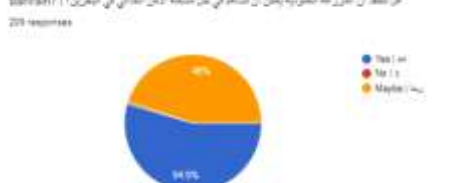
Do you think it is necessary for Bahrain to achieve agricultural self-sufficiency?
هل تعتقد أنه من الضروري أن يفس البحرين لتسليق إنتاجه ذاتي الزراعي؟



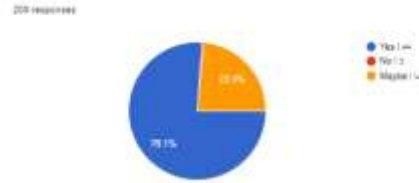
Have you ever been to a Vertical farm before?
هل زرت مزرعة عمودية من قبل؟



Do you think that a Vertical farm can contribute to solve the food security problem in Bahrain?
هل تعتقد أن المزرعة العمودية يمكن أن تساهم في حل مشكلة الأمن الغذائي في البحرين؟



If there is a Vertical farm in Bahrain, will you visit?
إذا كان هناك مزرعة عمودية في البحرين، هل ستزورها؟



A decision support discussion to select location for vertical farm in Bahrain

